

Attachment "8"

U.S. Large Hadron Collider (LHC) Project

Critical Decision-4B
Approval of 100% Completion/Project Closeout

DOE Fermi Site Office
DOE Office of High Energy Physics, Office of Science
NSF Elementary Particle Physics, Physics Division

Attachment "8"

Executive Summary

Meeting the many challenges of working on a large-scale international endeavor, the United States has now completed its major technical commitments to the Large Hadron Collider (LHC) and to the "A Toroidal LHC Apparatus" (ATLAS) and "Compact Muon Solenoid" (CMS) detectors. **This U.S. work comprises a \$531 million investment in the construction of the LHC, CMS and ATLAS that provides an opportunity to reap an enormous payoff expected in physics.** Through the U.S. LHC Project, U.S. objectives to contribute key equipment and technical support for design, construction and installation of major LHC detector and accelerator components, to maintain and extend U.S. technological capabilities in particle physics, and to advance international cooperation in the development and execution of large scientific projects have all been met in exemplary fashion. Through this investment, over 1,000 American physicists, engineers, students and technicians from 90 institutions nation-wide, currently including some 740 PhD scientists representing over one third of CMS and one fifth of ATLAS scientific authors, respectively, are working alongside colleagues from several dozen nations on the largest collaborative effort ever attempted in the physical sciences.

The Project was executed under the terms of an International Cooperation Agreement, signed in December 1997 between CERN, DOE and NSF, which specified the U.S. contribution to construction of the LHC, CMS and ATLAS. **The U.S. achieved its first major completion milestone on schedule in September 2005, Critical Decision-4A (CD-4A), completing delivery and initial assembly and installation of all items within U.S. control (amounting to ~97% of the total work).** This represented all U.S. project scope, except for the contributions that depended on international schedules, which had experienced delays because of the scale and complexity of the endeavor.

The few remaining percent of U.S. project scope beyond CD-4A involved detector-installation tasks, final acquisitions and fabrication of data-acquisition and silicon-tracker systems, completion of accelerator component deliveries, and issuing payments of final U.S. commitments toward detector common funds or for the completion of detectors, per international agreement. **This scope, consisting of \$21 million (including contingency) of the \$531 million total project cost, has now been completed within budget, and ahead of the September 30, 2008 CD-4B milestone for completion of the U.S. LHC Project.**

The work for the U.S. LHC Project conducted at our universities, national laboratories and at CERN has been executed diligently, professionally and safely, within the requirements of the respective institutions. U.S. management has emphasized the primacy of safety awareness in all activities. Members of the U.S. team stationed at CERN are well integrated into CERN's safety and training systems, and information on U.S. responsibilities regarding CERN's safety system, training, interfaces and contacts is maintained and made available to U.S. personnel. Collaboration on safety has ranged from addressing technical safety issues during construction, to training and approaches for reporting of incidents and sharing of lessons learned. Visits and exchanges between U.S. and CERN safety professionals and managers have paved the way for constructive dialogue and enhanced attention to safety.

The well established, ongoing joint DOE/NSF U.S. LHC Operations program has supported commissioning, pre-operations, maintenance and operations of U.S. components to prepare for LHC start-up and transition from construction to operations. This program provides the management oversight and resources for detector operations, maintenance, computing and upgrade R&D needed for continued successful U.S. involvement in CMS and ATLAS experiments. Under this program, Fermilab serves as the host and lead U.S. laboratory for oversight and management of the CMS and the accelerator-research programs, and BNL functions as the host U.S. laboratory for oversight and management of the ATLAS research program.

The tremendous success of the U.S. LHC project was based on the close national and international collaboration among some of the best technical and managerial experts available to face this challenging scientific project. The U.S. teams, whether comprised of groups from universities or national laboratories worked extraordinarily well together. The U.S. participants, including ANL, BNL, LBNL, Fermilab and the many universities, were not only significant contributors, but often led the international teams in providing key, state-of-the-art components, such as for the CMS hadron calorimeter, the ATLAS liquid argon

electromagnetic calorimeter, and high-precision silicon trackers and electron and muon identification subsystems. Technical challenges encountered along the way were resolved through close cooperation, sheer dedication and ingenious invention, providing great confidence that any difficulties in operations and data analysis will be met with equal imagination and energy, and will be successfully overcome.

In addition to the clear accomplishments, lessons have been learned and identified from the many successes and great challenges in the project, from some of the major risks involved, from the organizational and interface issues encountered, as well as other issues that had to be resolved. These were documented or shared in the CD-4A report or at meetings and workshops such as for planning of U.S. ITER, or the Global Science Forum on management practices for large international scientific projects. Some of the lessons learned are highlighted below:

- For large multi-agency projects, joint agency (e.g., DOE/NSF) coordination can provide highly effective project review, oversight, reporting and communications to meet the needs of all parties. For success, relationships among agencies should be well-defined and address the programmatic coordination required in the project.
- For projects centrally managed and overseen by national laboratories, strong support of laboratory management in the way of management systems and tools, resources and prioritization (in use of facilities as well as personnel) can be an essential contributor to the completion of a project.
- With opportunity for physics as a motivator, national laboratory and university groups can work together very effectively, using proven project-management tools and methods and a central project office, thereby leveraging unique expertise and resources to deliver major products on a large-scale.
- A phased CD-4 approach (A and B) enabled the project to declare successful completion of the majority of U.S. scope upon delivery of components, decoupling to a large extent from dependence and delays in the international project. This was possible because many of the sub-projects the U.S. took on were self-contained and, to the extent it was within U.S. control, the schedule was managed aggressively to stay off the critical path for international deliverables.
- Strong U.S. representation on the international bodies that address project, financial, technical and scientific matters provides important feedback and influence that can maximize the value of the U.S. contribution, and ultimately lead to the success of the international project.
- Early identification of specifications for interfacing and performance of deliverables, and robust quality assurance, testing and control of materials and assemblies under operational conditions to ensure design integrity is critical. This is particularly important where there are multiple boundaries of responsibility in large international projects. In a highly constrained cost or schedule environment, commissioning of integrated models, in lieu of physical testing, should be considered as a way to confirm design and performance.
- In large international projects, with multiple efforts proceeding in parallel, adequate budget contingency and schedule float is needed to accommodate evolution in design or specification, as well as developments and needs arising from logistics or integration of components from different sources into final assemblies.
- When builders of equipment are also its users, efficiency and continuity are assured in the transition from construction to maintenance and operations.

To conclude, with the successful completion of the work documented in this report, the more than ten-year-long U.S. LHC Project has reached its conclusion, within budget and on schedule. Overall, the United States has been a reliable and influential partner in the construction of the LHC accelerator components, and the ATLAS and CMS detectors, as well as in the leadership of these collaborations, each close to 2,000 strong world-wide. Working together, with indomitable spirit, these collaborations have built some of the largest and most complex scientific instruments ever conceived to further our understanding of the fundamental nature of matter and energy. The reach of the program at the LHC will be sensitive to anticipated new particles and physical phenomena, and the program is expected to have enormous impact on our understanding of the nature of mass, fundamental forces and the structure and origin of the universe. U.S. participation in the LHC provides the U.S. High Energy Physics community access to the next high energy frontier, and will help maintain U.S. world leadership in particle physics.

Critical Decision-4B
Approve 100% Completion/Project Closeout of the
U.S. Large Hadron Collider (LHC) Project
DOE Office of High Energy Physics, Office of Science
NSF Elementary Particle Physics, Physics Division

Purpose

This document presents the status for Critical Decision (CD)-4B, to "Approve 100% Completion/Project Closeout of the U.S. LHC Project", for review by the Energy Systems Acquisition Advisory Board (ESAAB) of the Office of Science. Reference 1 documented the DOE approval in October 2005 of CD-4A, to "Approve 97% Completion of the U.S. LHC Project," while this document presents the status of the final few percent of the U.S. LHC Project that brings it to completion.

The U.S. LHC Project was comprised of the U.S. CMS and U.S. ATLAS detector projects, and the U.S. LHC Accelerator project, representing the activities of U.S. universities and national laboratories required for the construction and delivery of the scientific and technical components ("deliverables") of the LHC program, as agreed to by the DOE, NSF and CERN. The baselines for these projects were originally approved in 1998.

Project Description

Funding for the U.S. LHC Project was initiated in FY96. In accordance with the International Agreement and Protocols, DOE and NSF were responsible for providing funding of \$250 million and \$81 million, respectively, for goods and services toward the fabrication of the ATLAS and CMS detectors. In addition, DOE provided funding of \$200 million for goods and services for the construction of the LHC accelerator, for a budget of \$531 million for the U.S. LHC Total Project Cost (TPC). The DOE contribution of \$450 million was budgeted from FY96 through FY07, while the NSF funding was budgeted from FY99 through FY03. As of CD-4A (September 30, 2005), the budgeted cost of work performed (earned value) amounted to \$510 million, leaving \$21 million, including contingency, to complete the remaining U.S. work for CD-4B, per the International Cooperation Agreement.

A two-phased project-completion plan was incorporated specifically into the project baseline, defining a Phase A (ending with CD-4A) and Phase B (ending with CD-4B). This was necessitated primarily to address international delays that impacted the completion of U.S. deliverables, caused by an intrinsic U.S. dependence on the CERN/LHC schedule for final underground detector installation, the rapidly changing areas of cutting-edge technology where as-late-as-possible purchase or fabrication was desirable, and international delays in decisions, procurement or delivery beyond U.S. control. Consequently, CD-4A represented the completion of 97% of U.S. project deliverables, including delivery and initial assembly or installation, except for those components for which the U.S. depended on the international status or schedule. The latter activities comprised only the final few percent of U.S. LHC project completion efforts needed for CD-4B approval, and are summarized below:

- *U.S. CMS project, Phase B - Installation/cabling of Endcap Muon and Hadron Calorimeter subsystems; Completion of the Forward Pixel and Silicon Tracker subsystems; Completion of minor activities for Trigger and Data Acquisition and Electromagnetic Calorimeter subsystems.***
- *U.S. ATLAS project, Phase B - Pixel production; completion of components of Silicon service panels; Trigger and Data Acquisition production; Completion of remaining installation and identified "punch-list" items (i.e. complete Liquid Argon front end board U.S. installation responsibilities and Muon subsystem electronics production).***

- ***U.S. LHC Accelerator project, Phase B - Final assembly/test of two Interaction Region (IR) quadrupoles; completion of last two IR quadrupole assemblies using KEK and CERN provided components; shipment of completed assemblies to CERN; completion of other identified "punch-list" items (e.g., re-work of specific components requiring repair due to inherent problems or damage during shipment).***

The U.S. CMS and U.S. ATLAS projects define completion of deliverables as equipment provided to CERN and installed in a sub-detector or detector assembly, consistent with U.S. responsibilities established in the project scope. For the U.S. LHC Accelerator project, completion of deliverables is defined through the completion of fabrication, testing and shipment to CERN of the U.S. LHC hardware deliverables. The scope of deliverables for each project has been maintained and managed in accordance with the change-control process defined in the Project Management Plans of each project.

The total cost of completing the above tasks to support CD-4B, including contingency, amounted to \$21 million. The projects have been executed so as to maximize the value of the U.S. contribution to the construction of the LHC and the ATLAS and CMS experiments. This has been performed in close coordination with the international collaborations and in accordance with the terms and funding specified in the International Cooperation Agreement.

Requirements for Critical Decision-4B

The requirements for CD-4B are completed:

- ***U.S. CMS detector deliverables for Phase B have been completed, see Reference 2, "U.S. LHC Project CD-4B Closure Report for U.S. CMS" for the detailed breakdown of the work.***
- ***U.S. ATLAS detector deliverables for Phase B have been completed, see Reference 3, "U.S. LHC Project CD-4B Closure Report for U.S. ATLAS" for the detailed breakdown of the work.***
- ***U.S. LHC Accelerator deliverables for Phase B have been completed, see References 4 and 5, memos concerning completion of the U.S. LHC Accelerator project scope and Reference 6, Transfer of Title documents for DOE transfer and CERN acceptance of ownership for all U.S. LHC Accelerator project deliverables.***
- ***The overall U.S. LHC Project has met the definition of CD-4B, i.e., U.S. LHC Project has achieved 100% completion before September 30, 2008.***

The U.S. LHC CD-4B Closure Reports certify that the final Phase B project-baseline scope is completed as described, and that the Maintenance & Operations planning/transition for this final portion of detector work has been accomplished. These reports document the submission and acceptance of the final U.S. items and deliverables for Phase B. **These reports only document completion of those items that were not reported as 100% complete at CD-4A.**

Transition from Construction to Operations

The U.S. CMS, U.S. ATLAS and U.S. LHC Accelerator projects have provided appropriate safety documentation to CERN, consistent with the U.S. role in the design, fabrication, installation or testing of the relevant equipment or subsystems. Through activities such as engineering design reviews, technical design reports, system safety reviews, failure mode & effects analyses, supporting calculations, safety tests, and through addressing CERN technical safety and inspection requirements and recommendations, the U.S. projects fully integrated safety reviews and assessments into its work. The relevant documentation is maintained primarily in the CERN document-management system. **The U.S. detector projects have played a strong role in the technical coordination of CMS and ATLAS, addressing specifications and agreements related to system integration and safety during detector installation, commissioning, and maintenance and operations activities.**

A Task Force set up by U.S. LHC Joint Oversight Group (JOG) evaluated both overall CERN and experiment-specific safety training, and concluded that the CERN safety training program is appropriate, very similar to U.S. safety training, and sufficient to meet safety training needs for U.S. personnel. CERN is implementing an enhanced formal Safety Management System that strengthens line management for safety in the technical departments, strengthens the technical safety capabilities in the departments, and organizes the CERN Safety Commission into an auditing function for additional oversight. CERN's environmental management system is based on the ISO 14001 Environmental Management Standard. U.S. personnel at CERN are required to know and adhere to CERN's ES&H rules, programs and work procedures. Also, the U.S. CMS, ATLAS and accelerator collaborations promote safety awareness within their groups through meetings and internal communications.

CERN's and collaborations' safety interfaces for U.S. personnel are well defined. In the transition from construction to operations, a Group Leader in Matters of Safety for each experiment remains a primary interface, with a Shift Leader in Matters of Safety assigned to assure proper safety procedures during shift operations. Independent Safety Coordinators from the construction phase have also transitioned to provide oversight of operations. Safety awareness is a high priority for the U.S. management and collaborators. Up to date information on U.S. personnel responsibilities regarding CERN's safety system, training, interfaces and safety and management contacts is maintained and made available via e-mail, web and worksite postings to all U.S. CMS, ATLAS and Accelerator collaborators.

A JOG Task Force also evaluated and made recommendations concerning communications protocols on safety issues at CERN, and these have been implemented for accident and near-miss incidents. In particular, collaboration management notifies representatives of U.S. institutions of any significant incidents, and they distribute the relevant information to their members. Managers of U.S. CMS, ATLAS and Accelerator research programs inform the DOE and NSF Program Managers, and follow up on any issues that could provide lessons learned to be communicated from the results of CERN and collaboration investigations and findings. The U.S. managers also engage the ES&H management at U.S. Host Labs (Fermilab for CMS/Accelerator or BNL for ATLAS), as appropriate, for advice. Sharing of safety information among U.S. Labs and U.S. groups also occurs. Recent exchanges and visits between U.S. Host Labs and CERN ES&H management have confirmed safety implementation, safety priority and clarified the developments at CERN, laying further groundwork for future communication and safety exchanges.

Transition to operations for U.S. involvement in LHC experiments is fully addressed through the U.S. LHC Operations Program. The U.S. LHC construction project included installation activities for U.S. produced CMS and ATLAS detector components, but did not include commissioning of detector or accelerator components. In addition, there were no U.S. LHC Project responsibilities defined for the installation of U.S. produced accelerator components. Commissioning and other pre-operations activities, along with maintenance and operations for U.S. LHC Project deliverables form the elements of the U.S. LHC Operations Program. Consistent with the U.S. roles and responsibilities in the international LHC collaboration, the U.S. LHC Operations Program has supported preparation of detector operating and maintenance procedures by U.S. groups, U.S. participation in assessments of operational readiness of detectors, or equivalent reviews required by CERN, and development and provision of U.S. operations and maintenance personnel needed to support U.S. scientific and technical involvement in the LHC experiments.

Project Completion

In accordance with the two-phased project-completion plan, the CD-4B milestone is defined as "U.S. LHC Project 100% Complete, by September 30, 2008". This milestone is met upon completing the remaining scope in Phase B, consisting of detector installation tasks, final acquisition and fabrication of detector data acquisition and silicon systems, and completion of remaining

deliverables delayed through international causes. The completion of this scope is documented in the U.S. LHC Project CD-4B Closure reports and References 2-6. Attachment 1 provides the table that shows the completion costs and earned value for the total U.S. LHC Project. Attachment 1 tabulates the costs of the completed U.S. LHC Project, with the CD-4B requirements met as documented in the References.

The U.S. LHC Project CD-4B Closure Reports also document minor "punch-list" items. These items do not impact the completion of the U.S. LHC Project nor impact the international project schedules. The punch-list items will be tracked to completion along with any financial closeout or final cost reports necessitated by any delay in final invoicing for the actual costs.

Along with those highlighted in the summary, additional lessons learned are documented in references 1-3.

Attachment 1- U.S. LHC Project Completion Table

References

1. U.S. LHC Project CD-4A Decision and Approval Document
2. U.S. LHC Project CD-4B Closure Report for U.S. CMS
3. U.S. LHC Project CD-4B Closure Report for U.S. ATLAS
4. Memo, Subject: Completion of the U.S. LHC Accelerator Project; U.S. LHC FPD to AD-OHEP; September 20, 2006
5. Memo, Subject: U.S. LHC Accelerator Project punch-list completion; U.S. LHC FPD to OHEP/U.S. LHC Accelerator Assistant Program Manager; March 14, 2007
6. Transfer of Title documents, documenting DOE transfer and CERN acceptance of ownership for U.S. LHC Accelerator project deliverables

Attachment 1 – U.S. LHC Project Completion Table

U.S. LHC Project Completion Costs for CD-4B Project Closeout

Earned Value thru 5/31/2008	\$K Total Project Cost	Budgeted Cost of Work Performed (BCWP)	Budget at Completion (BAC)	% Complete BCWP/BAC
US CMS	167,250	167,244 ^o	167,244	100
US ATLAS	163,750	163,750 [*]	163,750	100
US LHC Accelerator	200,000	200,000 [*]	200,000	100
US LHC Total	531,000	530,994	530,994	100

- ^o Positive cost variance due to Actual costs < BCWP; financial closeout will include final payment to CMS using remaining funds within the TPC, per International Agreement
- ^{*} BCWP = Actual Costs; includes remaining contingency funds used as final common fund payment to ATLAS, per International Agreement
- ^{*} BCWP = Actual Costs; includes cost of fabrication, testing and delivery of U.S. components and U.S. reimbursement to CERN for purchases from U.S. industry, per International Agreement

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Date

**U.S. Large Hadron Collider (LHC) Project
ESAAS for Critical Decision-4B**

Representative:

The undersigned "Do Recommend" (Yes) or "Do Not Recommend" (No) approval of Critical Decision-4B, regarding Initial Design Completion and Budget Claimant for the U.S. LHC Project, as shown below.



ESAAS Evaluation, Project Assessment Date

Yes ☒ No ☐



Representative, Non-Proposed SC Program Office Date

Yes ☒ No ☐



Representative, Office of Budget Date

Yes ☒ No ☐

Representative, Environment Safety & Health Division Date

Yes ☐ No ☐



Representative, Security Management Team Date

Yes ☒ No ☐

Representative, Laboratory Infrastructure Division Date

Yes ☐ No ☐

Representative, Grants and Contracts Division Date

Yes ☐ No ☐

The project has been completed on schedule, within the Total Project Cost (TPC), and has met the baseline scope requirements for completion, as documented in the reference reports.

~~CONFIDENTIAL~~

Richard T. Ables

Richard T. Ables
Under Secretary of Science

June 25, 2008